GRI Fuel Cell Perspective

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Outline

A. Power Generation Perspective
B. Basic Research on Solid Oxide Fuel Cells

GRI Power Generation Strategic Elements

1. Use of Natural Gas in (1) competitive dispatch — central station; and (2) emissions control — central station.

2. Customer Generation — onsite.

3. Distributed Generation — utility controlled.

GRI's Changing Imperatives

1. The gas industry is rapidly evolving from full-cost recovery to market pricing.

2. There is an increasing perception that share-holder dollars, rather than rate-payer dollars, are at risk.

3. Share-holder dollars carry a **much higher** discount (investment hurdle) rate.

4. The R&D portfolio must equilibrate to a higher discount rate **and** reduced resources.

GRI Response

1. Re-examine project time frames, risk factors, and expected benefits.

2. Develop a lower-risk, nearer-term R&D portfolio.

3. No 1997 applied R&D fuel-cell budget or activities, although basic SOFC research continues.

Where Do Fuel Cells Fit?

- **Onsite Generation**

  Premium Power - applications needing sine-waves, not volts and amps; energy costs defer to other cost factors.

  Configuration - base-load fuel cell on a dedicated circuit with grid as backup. *Fuel cell reliability must be unquestioned.*

- **Distributed Generation**

  Definition: modular generation under the dispatch control of electric utilities.

  GRI focus on characterizing distributed generation benefits, and defining required technology features.

  Application pull, not technology push.

  Gas turbine and reciprocating engine technologies continue to progress.

  Vast network of unknown costs. Price transparency will uncover pockets of very high cost service.

  Performance-based rate-making will motivate wire companies to a least-cost solution.

  Is modular generation cheaper than substations and wires? Probably **yes** in enough cases to support multiple vendors.

GRI View of Fuel Cell Status

1. The continuing challenge for the PAFC is to find high-value, mission-critical power niches that can easily afford the high first cost.

2. Recent MCFC test results point out how much research is still needed, while the MCFC slowly progresses toward product goals.

3. Basic research focuses on the SOFC because of its advantages for stationary applications, but is also monitoring the recent PEM progress.

SOFC Advantages in Stationary Applications

- Natural gas fuel is processed directly within the stack — by internal reforming or possibly by direct oxidation.

- One compact system with effective heat transfer from the stack to reforming and air preheating steps.

- Long life because of the all-solid-state construction.

- Very high efficiency: SOFC only — 55 percent HHV; SOFC and Gas Turbine Cycles — 65 to 70 percent HHV.

- High quality heat for direct use, or gas turbine cycles.

Current GRI SOFC Research

1. Reduced-temperature, planar systems (AlliedSignal, Univ. of Utah, Univ. of Pennsylvania)

    - Anode-supported, thin-film, scaled-up cells
    - Mixed-conducting electrode cells, CH_4 oxidation
    - Inexpensive fabrication
    - Small stacks, metallic interconnects

2. Tubular systems (Westinghouse)

    - Fabrication methods
    - Cell design

3. Technical evaluation (TDA Research, Bechtel)

    - Manufacturing cost, system issues

Planar Manufacturing Cost Assumptions

200 MW/yr, 24 hr/day operation, 95% availability

Fixed capital investment:	3.9 times major equipment
Working capital:	20% of fixed capital
Raw materials:	vendor projections
Labor:	200 employees at $35,000/year
Maintenance:	4.2% of fixed capital
Depreciation:	10% of fixed capital
Property taxes and insurance:	2.6% of fixed capital
Overhead & administration:	8% of labor
Distribution, marketing, and R&D:	15% of total pretax expense
Profit:	Adjusted for ROR of 20%
Income taxes:	50% of profit

ROR = (depreciation + profit - income tax)(fixed + working capital)
Annual cost = raw materials + operating + capital-related
Stack capital cost = (annual cost)(annual production)

Conclusions

1. Rapid changes in the energy industry have produced a nearer-term focus in GRI's power generation program.

2. Applied R&D is supporting improvements to microturbines, engines, and industrial turbines.

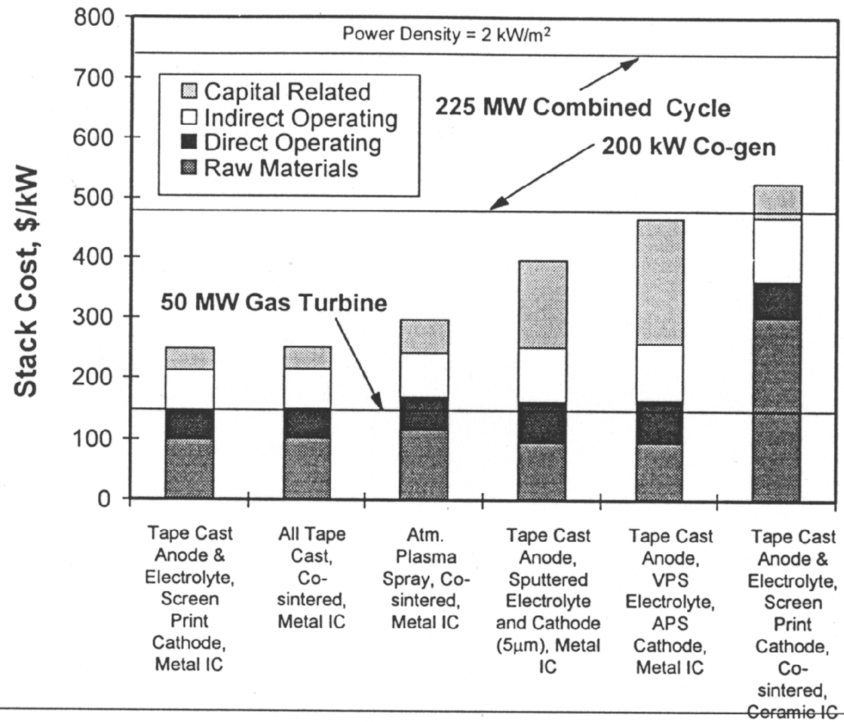
3. Basic research in reduced-temperature, planar SOFCs:

   - Technically challenging, longer-term option
   - Potential for more than $700/kW capital cost
   - Higher power density, small size, good manufacturability

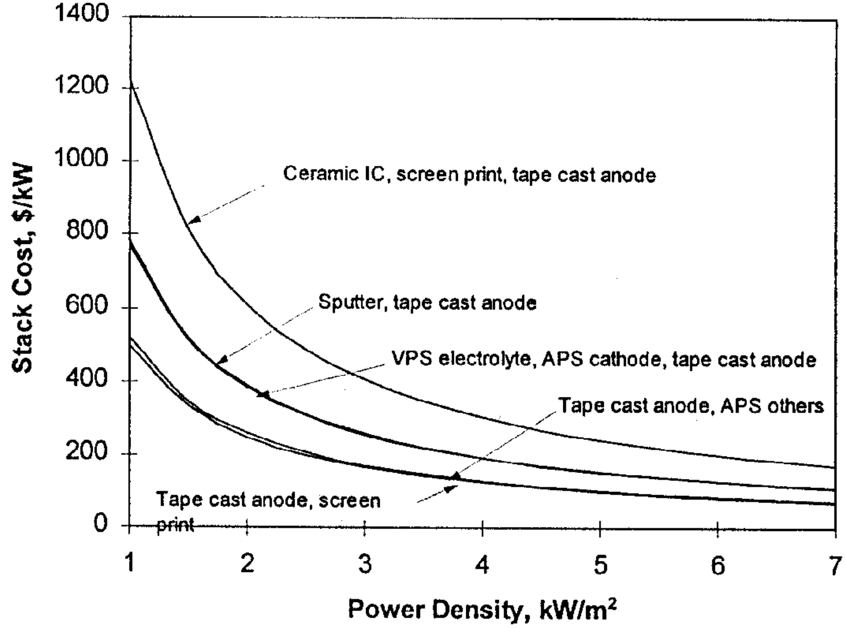
4. Basic research in tubular SOFCs:

   - Possibly ready for commercialization in about 3 years
   - Seal-less design, tolerance to thermal stress, recent technical progress, operability in high-efficiency, pressurized SOFC/turbine cycles

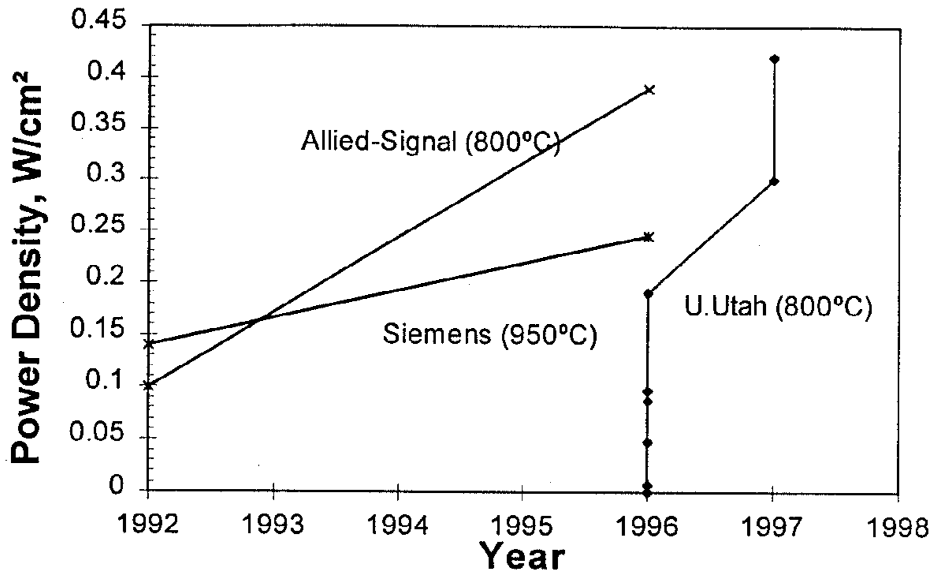
SOFC STACK MANUFACTURING COSTS



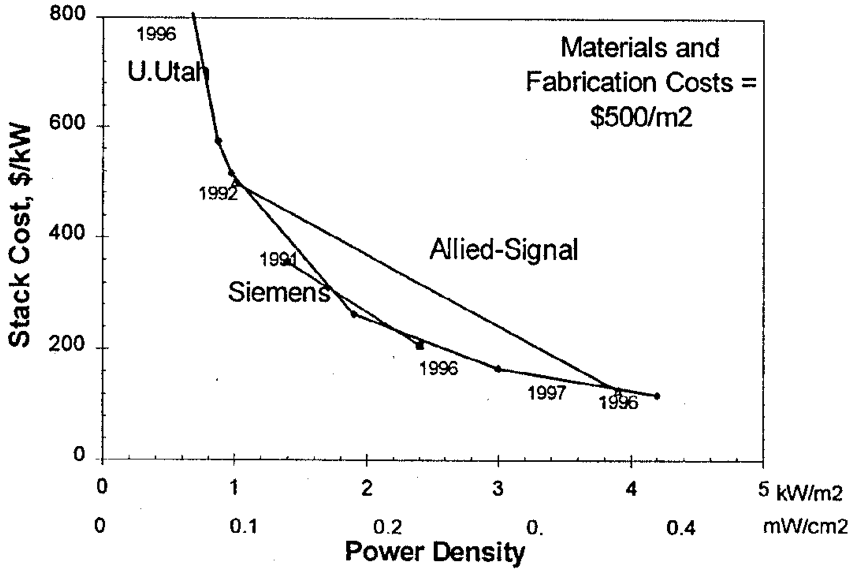
EFFECT OF POWER DENSITY ON SOFC STACK COST

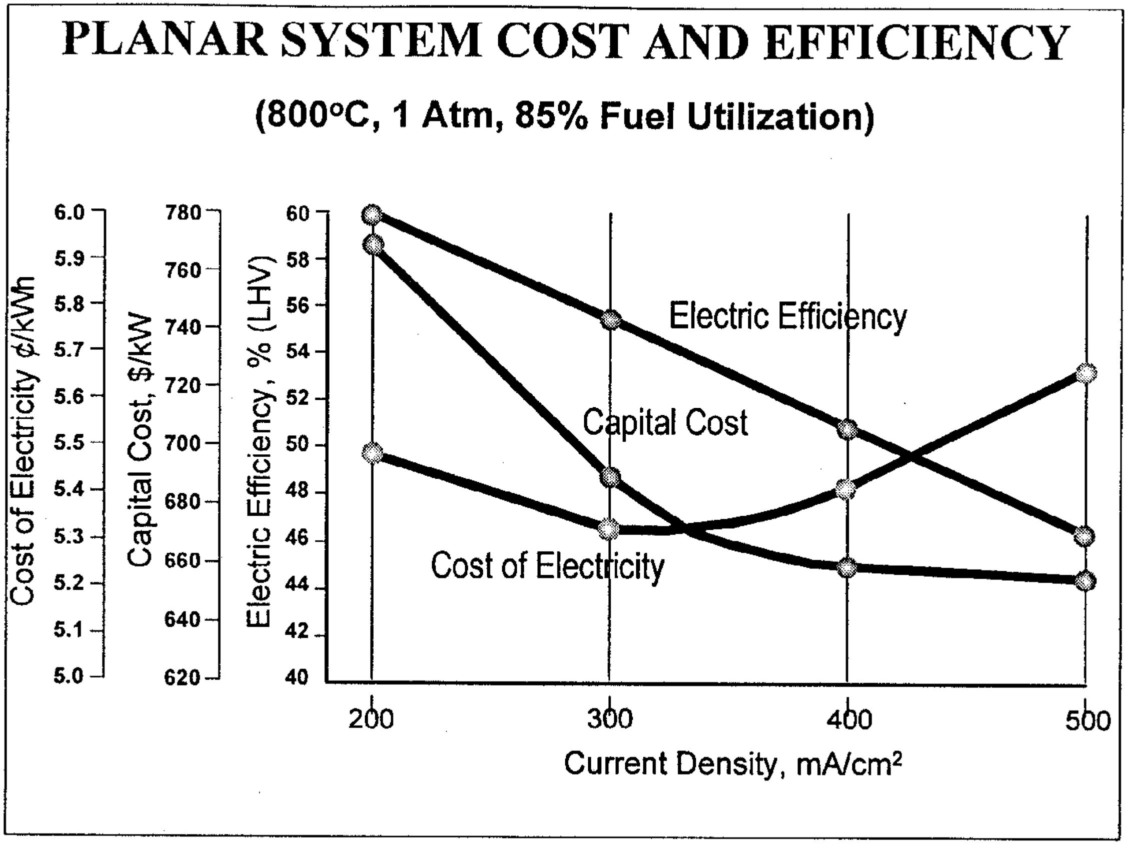


COMPARISON OF PLANAR GEOMETRY STACK POWER DENSITIES



THE COST OF SOFC STACKS IS DECREASING AS POWER DENSITY IS IMPROVED




PLANAR SYSTEM COST AND EFFICIENCY
(800°C, 1 Atm, 85% Fuel Utilization)
Cost of Electricity ¢/kWh
Capital Cost, $/kW
Electric Efficiency, % (LHV)
6.0
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5.0
780
760
740
720
700
680
660
640
620
60
58
56
54
52
50
48
46
44
42
40
Electric Efficiency
Capital Cost
Cost of Electricity
200
300
400
500
Current Density, mA/cm²